

**Effectiveness of Action Observation Training with Immediate Physical Practice for  
Improving Hemiparetic Upper Limb Function in Chronic Stroke**

By

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This thesis is submitted in partial fulfilment of the requirements for the award of

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## STUDENT DECLARATION

I, *Kita Sugg*, do hereby declare that:

- a) Except where due acknowledgement is made, the work is that of the candidate alone;
- b) The work has not been submitted previously, in whole or in part, to qualify for any other academic award;
- c) The content of the thesis is the result of work which has been carried out since the official commencement data of the approved research program;
- d) Ethics procedures and guidelines have been followed.

Signed:

Date:

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“No duty is more urgent than that of returning thanks.” ~ St. Ambrose of Milan

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## LIST OF ITEMS COMPLETED REVELANT TO THE THESIS

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## TABLE OF CONTENTS

STUDENT DECLARATION.....	I
ACKNOWLEDGEMENTS.....	II
LIST OF ITEMS COMPLETED RELEVANT TO THE THESIS.....	III
TABLE OF CONTENTS.....	IV
LIST OF TABLES.....	VI
LIST OF FIGURES.....	VII
<b>SUMMARY OF THE RESEARCH.....</b>	<b>1</b>
<b>Structure of the Thesis.....</b>	<b>2</b>
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>3</b>
<b>CHAPTER 2: LITERATURE REVIEW.....</b>	<b>6</b>
Relationship between Observation of Action and Action Execution.....	6
Behavioural level.....	6
Neural level.....	8
Enhancement of Motor System Priming Through Action Observation.....	9
Stroke.....	10
Neuroplasticity.....	12
The Healthy Brain and the Stroke Brain.....	13
Action Observation with Physical Practice for Upper Limb Recovery after Stroke...	14
Summary.....	21
Rationale for the Research.....	21
<b>CHAPTER 3.....</b>	<b>24</b>
Abstract.....	24
Introduction.....	25
Method.....	27

Participants.....	28
Research Design.....	29
Procedure.....	31
Measures.....	33
Data Analysis.....	36
Results.....	37
Discussion.....	42
Conclusions .....	44
<b>CHAPTER 4: CONCLUSIONS .....</b>	<b>46</b>
<b>REFERENCES.....</b>	<b>49</b>

## LIST OF TABLES

<b>Table 1.</b>	Demographics: Participants with chronic stroke, characteristics and values at time of recruitment.....	30
<b>Table 2.</b>	Individual participant scores and group values for all outcome measures across time series testing points.....	38
<b>Table 3.</b>	Themes drawn from participant responses to structured interviews conducted post-test 1 and post-test 2.....	41

## LIST OF FIGURES

<b>Figure 1.</b>	Consort Diagram of Sampling and Flow of Participants.....	28
<b>Figure 2.</b>	Time Series Design of Experiment and Action Observation Training Session Timeline.....	31
<b>Figure 3.</b>	Still Image Examples of the Dynamic Video Footage Shown During Training Phases.....	32
<b>Figure 4.</b>	Group Means for Fugl-Meyer Assessment of the Upper Extremity Over Testing Time Points.....	39



## **SUMMARY OF THE RESEARCH**

Hemiparesis of the upper extremity has a large impact on functional capabilities following stroke. Recovery time after stroke varies greatly with some patients undergoing some spontaneous recovery, but for the majority recovery occurs over a period of many months to several years. Recovery after stroke can be further enhanced with rehabilitation techniques. Rehabilitation following stroke aims to minimise motor impairment through encouraging neuroplasticity. Action observation has been shown to increase activation of the motor cortex. Increased activity in the motor cortex during action observation is attributed to the mirror neuron system. The mirror neuron system is active when actions are performed as well as when we observe another person performing the same action. In the stroke populations action observation training has been shown to significantly improve motor function of the hemiparetic upper limb. However, literature on the use of action observation for recovery of upper limb function after stroke is limited.

The purpose of this honours thesis was to advance the existing literature on action observation use in stroke for improving hemiparetic arm and hand function. Attention was given to the duration of observation prior to physical practice, to optimise use of motor system priming. Comparison was made between the use of action observation and physical practice as well as relaxation-sham control. Participants acted as their own controls completing a control phase with relaxation-sham to establish a baseline measure with physical practice. With baseline established participants went on to the action observation training phase, observing motor skills for 30 seconds before practicing them.

Manuscript structured experimental report can be found in chapter three of this thesis. The findings showed improvement to measures of the hemiparetic arm and hand function in both the control and action observation training phases, with greater improvements seen with action observation training. Additionally, participant self-efficacy continued to improve

throughout the training phases as indicated by self-perceived measures of the hemiparetic arm and hand function and confidence. These preliminary findings are mere stepping stones to further investigation of action observation training for rehabilitation after stroke.

### **Structure of the Thesis**

This thesis is structured as follows: (a) chapter one introduces stroke and the importance of new rehabilitation techniques for the recovery of upper limb function and the value of action observation for stroke rehabilitation, (b) chapter two reviews literature relevant to the theories underpinning action observation, potential for enhanced benefits from action observation training, provides a general overview of stroke and aims of recovery after stroke, proceeds to review neuroplasticity, investigation of the healthy brain and the stroke brain and previous studies examining action observation plus physical practice for upper limb recovery in stroke, followed by the rationale for the experiment conducted in this thesis, (c) chapter three covers the experiment conducted for this thesis structured as a manuscript for journal submission, and (d) chapter four presents conclusions and implications resultant from the experiment. A reference list of literature and sources cited in the chapters of this thesis follows the cessation of chapter five.

Chapter three has been kept brief in order to fulfil word limit (4000 words) requirements for submission to Journal of Neurorehabilitation and Neural Repair for consideration of publication. This thesis is written and referenced according to the Publication Manual of the American Psychological Association (6<sup>th</sup> Edition) (American Psychology Association, 2010), which is the standard format for a thesis in the sub-discipline of Motor Control and Learning. Due to the structure of the thesis mentioned above, there is unavoidable repetition in certain sections.

## **CHAPTER 1**

### **Introduction**

Each year 15 million people worldwide suffer a stroke, resulting in permanent disability in one third of cases (World Health Organisation, 2011). Thirty one percent of disability-adjusted life years (DALYs) worldwide are due to stroke (World Health Organisation, 2011). These figures contribute to stroke being the leading cause of disability amongst high income countries and a leading cause of disability in low to moderate income countries after dementia (Australian Bureau of Statistics, 2012; Go et al., 2012; World Health Organisation, 2011). In Australia 56% of people living with disabilities caused by stroke require assistance from carers in activities of daily living (Australian Institute of Health and Welfare, 2012). In Western Australia 29,475 stroke survivors are living with a disability that prevents them from being able to perform activities of daily living unassisted (Australian Bureau of Statistics, 2012). These figures highlight the importance of stroke rehabilitation to enable stroke survivors to reclaim their independence.

Hemiparesis results in approximately 80% of strokes with weakness to one side of the body (Pulman & Buckley, 2013). Long-term impairment to motor function of the hemiparetic upper extremity affects 40-45% of chronic stroke survivors (Dromerick et al., 2006; McCrea & Eng, 2005). Hemiparesis results in loss or impairment to motor function on the affected side (Han, Wang, Meng, & Qi, 2013). Hemiparesis is commonly presented in stroke to the cerebrum, with the side affected by hemiparesis corresponding to the hemisphere of the cerebrum affected. Right side hemiparesis is a result of stroke to the left hemisphere and left side hemiparesis the result of stroke to the right hemisphere (Lindley, 2008).

With the increasing demands on the health system rehabilitation of lower limb functional recovery has taken precedence, limiting attention for upper limb rehabilitation and recovery (Australian Institute of Health and Welfare, 2012). Upper limb impairment causing

a lack of functional ability can have a substantial negative affect on quality of life, through restriction of daily activities such as the capability of stroke survivors to feed themselves (The National Stroke Foundation, 2013). The need for rehabilitation techniques to improve upper extremity function in chronic stroke is crucial to enhance quality of life for stroke survivors and reduce DALYs.

Recovery after a stroke is focused upon intense physical rehabilitation programs usually involving repetitive practice of movements with the impaired arm, to encourage neuroplasticity (Cantarero et al., 2011). Some rehabilitation techniques, such as robotic assisted therapy, require expensive equipment and therapist supervision (Lo et al., 2010). Finding cost effective upper limb rehabilitation techniques that can be applied in an array of settings; in-patient, out-patient and by the stroke survivor at home would be valuable to enhance recovery. One cost effective technique that has potential for stroke rehabilitation is action observation training. Action observation training involves observing another individual perform a movement, which has been reported to promote brain plasticity and improve function (Small, Buccino, & Solodkin, 2012). The theoretical concept of action observation training is based upon activation (or priming) of brain areas that are normally involved in movement execution, whilst only observing the same movement (Bhasin, Padma Srivastava, Kumaran, Bhatia, & Mohanty, 2012). The use of action observation as training can easily be delivered through in-person demonstrations of actions or via pre-recorded video footage of actions. Use of pre-recorded video footage that can be structured on Digital Video Discs (DVDs) allows for stroke survivors to complete training in the comfort of their own home and eliminates costs involved with one-on-one training with a therapist. Through activation (priming) of brain regions involved during action execution, action observation provides a mechanism for motor skill relearning despite physical impairments (Garrison, Winstein, & Aziz-Zadeh, 2010).

Activation of brain regions with action observation training is attributed to the mirror neuron system (Buccino, Solodkin, & Small, 2006). The Mirror Neuron System is comprised of neurons which are activated when an individual observes movements performed by others, and when the individual performs the movement themselves (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). This link between perception of actions and movement execution, demonstrates a shared neural network. Through activating shared motor networks, action observation can serve to prime the motor system for subsequent physical practice of actions.

Studies, including those by Ertelt et al. (2007) and Franceschini et al. (2012) have examined action observation as a rehabilitation tool for priming the motor system to achieve adaptive plasticity and improve upper limb function. Behavioural and neural level evidence indicated increased functional improvement in the experimental group undergoing action observation compared to the control group. The research experiment completed relevant to this honours thesis employed action observation training with physical practice for improve function of the upper limb in chronic stroke survivors. The purpose of this honours project is to advance theoretical understanding of action observation training from a behavioural level of analysis based upon existing theoretical and empirical knowledge of the mirror neuron system, the common-coding hypothesis and neuroplasticity. In addition to adding to the limited literature, unique elements in the methodology were included to further understand the value of action observation training to stroke rehabilitation. Unique elements included in the experiment provided physical practice immediately following observation of each motor skill in an attempt to optimise motor system priming and evaluation of participants' perceptions of their functional recovery.

## CHAPTER 2

### Literature Review

The following literature review covers: (i) the relationship between observation of action and action execution at the behavioural level and the neural level, (ii) premises of enhancing activation of the mirror neuron system during action observation, (iii) overview of stroke and the impact of upper limb hemiparesis, (iv) the role of neuroplasticity in motor learning and recovery, (v) comparison of the healthy brain to the stroke brain during action observation, and (vi) literature investigating the use of action observation with physical practice for recovery of hemiparetic upper limb in stroke.

#### **Relationship between Observation of Action and Action Execution**

A relationship exists between observation (perception) of actions and action execution (performance). Motor areas in the brain activate during observation of action performed by another individual, resembling activation of these motor areas with performance of the same action (Buccino, Binkofski, & Riggio, 2004).

**Behavioural level.** The common-coding theory describes a link between perception; the pickup of visual information and action; the execution of movement (Prinz, 1997). The common-coding theory has been established through numerous behavioural studies, showing that purely observing physical performance of an action can lead to improvement in performance of a motor skill (Cantarero et al., 2011). Examination of the common-coding theory has also revealed a greater activation of motor areas, when movements are observed with intent to imitate compared to observing for other reasons, i.e., observation for judging the quality of movement (Zentgraf et al., 2005).

Cross, Kraemer, Hamilton, Kelley, and Grafton (2009) investigated the action observation network in a behavioural study with examination of three training conditions; physical practice, observed and untrained. The examined training conditions were delivered

using a dance-learning type video game. The video game employs a mat which acts as the controller, providing feedback to the screen as moves (steps in dance) are executed on the arrows on its surface. Dance sequences are taught with arrows indicating directions relevant to their position on the mat moves are executed on. Movement cues for the trained dance sequence appear on the screen seconds before the movement is to be executed. Two types of cues were used to present dance sequences; the arrows indicating movement direction seen alone and those where an expert dancer was shown performing the dance sequence in time with the arrows superimposed over the top. The three training conditions; physical practice (danced), observed (watched) and untrained (dance sequences not danced or watched during training) and the two cue types formed a 3 x 2 design. Sixteen healthy participants were recruited and trained on the dance-learning video game for five days. Eighteen different dance sequences were created for the behavioural study, with participants watching the same 6 sequences and dancing the same 6 sequences each day. The remaining 6 sequences were not shown during the five days of training, making up the untrained condition for testing. The cue type shown in the conditions were split, with three of the sequences showing arrows alone and the other three showing the arrows superimposed over the expert dancer. Behavioural assessment was an evaluation of information on accuracy of steps in relation to arrows and timing of movements as recorded by the dance mat. Results showed a significant improvement in dance performance for practiced dance sequences, indicating the positive effect of the training (physical practice) on motor-learning of dance sequences. A significant difference was seen between dances and untrained but not between danced and watched or watched and untrained, indicating best performance improvement in danced sequences, followed by watched sequences and worst performance on untrained sequences. The authors concluded that observation of movement sequences exhibits greater improvement in

subsequent performance compared to untrained sequence. Further, the authors attributed the reported improvements seen with observation of sequence to the action observation network.

This link between observation of action and action execution has been established at the neural level with brain imaging measures. Neural level evidence demonstrates the presence of mirror neurons which are activated during both the observation of action and the execution of actions.

**Neural level.** After the 1980's discovery of a system matching action observation and execution (the mirror neuron system) in monkeys (Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981), Fadiga et al. (1995) conducted a magnetic stimulation study in order to uncover if the same system is present in humans. Twelve healthy humans were recruited and participated in each of the four experimental conditions. The four experimental conditions involved observation; action observation of another person manipulating an object, action observation of another person without object manipulation, observation of the fore mentioned object alone without human interaction and observation to detect dimming of a light. Half of the participants did not perform any movements during the experiment, they purely observed while the remaining six participants performed the actions they had observed. Electromyography (EMG) was used to record motor evoked potential (MEP) in muscles involved in the observed movements. Significant increases to MEP were seen with action observation conditions, but not during observation of the object or when detecting the light dimming. Furthermore, increases in MEP were larger during action observation with object manipulation compared to action observation without object manipulation. In participants that performed the actions following observation, recorded MEP patterns were similar to those produced during action observation. Fadiga et al. (1995) findings confirmed that the system linking action observation and execution (the mirror neuron system) found in monkeys, does exist in humans (Fadiga et al., 1995). Additionally, larger increases in MEP



seen in the session of action observation where object manipulation was observed could indicate a potential for use of motor skills involving objects for enhance benefits.

The mirror neuron system is active during observation of another individual performing an action and when the observer performs the motor skill themselves (Buccino et al., 2001; Fadiga et al., 1995). Accordingly, the mirror neurons activate during observation 'mirroring' activation during action performance (Iacoboni & Mazziotta, 2007). Mirror neurons are found in motor areas of the brain; in the frontal (control of voluntary movement) and parietal lobes (perception and sensory information centre). These motor areas are the inferior frontal gyrus, ventral premotor cortex and the rostral inferior parietal lobule (for a review, see Garrison et al. (2010). Based upon their neuroanatomy, the mirror neuron system provides a shared network between perception (parietal lobe) and action (frontal lobe). Therefore, activation of the mirror neuron system can be promising in retrieving motor representations for recovery after stroke (Cantarero et al., 2011).

### **Enhancement of Motor System Priming Through Action Observation**

The constant pursuit to enhance use of action observation, has driven investigation of aspects that contribute to activation and those that can possibly optimise activation of the mirror neuron system and motor system priming.

For example, Calvo-Merino, Glaser, Grezes, Passingham, and Haggard (2005) examined action observation of acquired motor skills versus those motor skill that have not been learnt, to determine the influence of motor expertise on activation during action observation. Expert dancers with training solely in ballet (n = 10) or capoeira (n = 9) were recruited, along with ten non-dancing participants. Primary outcome measure of brain activity was collected using functional magnetic resonance imaging (fMRI). Alteration in brain activity is detected by changes in blood flow and oxygen levels as the active areas of the brain consume increased amounts of oxygen. Each participant view ballet and capoeira video

footage, each dancer viewed their own style and the unfamiliar style and non-dancers viewed all video footage. Resulting fMRI measures taken during these observations indicated activation of the mirror neuron system during action observation for all participants.

Activation seen during observation of actions not learnt is proposed to be attributed to the mirror neuron systems ability to use motor stimulation to integrate and match actions to those similar in their own motor representations (Buccino et al., 2004). As predicted by Calvo-Merino et al. (2005) stronger activation of the mirror neuron system was seen when the expert dancers observed video footage of their dance style. Findings suggests that motor expertise does influence the sensitivity of the mirror neuron system (Calvo-Merino et al., 2005).

The concept of motor expertise maximising the link between perception and action by increasing sensitivity of the mirror neuron system could be transferred to the use action observation as a rehabilitation tool. Expertise is found in the automatic performance of tasks in day to day life. Observation of every day functional tasks may provide stronger activation of the mirror neuron system.

## **Stroke**

Stroke occurs when blood supply to the brain is disrupted and part of the brain stops functioning (Lindley, 2008). Function in affected part of the brain ceases within seconds and tissue damage is evident after two minutes of being starved of oxygen and chemical substrates, which the blood would normally deliver (Murphy & Corbett, 2009). The primary cause of stroke is cerebral infarction involving a blockage or occlusions to blood supply, usually due to a blood clot (Wojner-Alexander, Garami, Chernyshev, & Alexandrov, 2005). Blood thinners such as anticoagulants and antiplatelet medications are used in emergency treatment of cerebral infarction, preventing the clot from growing and further clots from dislodging (Lindley, 2008). Primary intracerebral haemorrhage is the second main cause of

stroke, occurring when a blood vessel in the brain bursts or leaks (Langhorne, Coupar, & Pollock, 2009). Blood clotting agents are administered to begin clotting process at the site of leak, trapping red blood cells and reducing further haemorrhage (Chabner, 2007). Stroke can occur anywhere in the brain, presenting with sudden onset of symptoms depending on the area(s) of the brain affected. Symptoms experienced range from a rapidly fatal illness to a minor loss of sensation on one side of the body (Lindley, 2008).

Stroke symptom duration varies with some symptoms, such as vision loss, dispersing within weeks and others causing long-term impairment. Stroke severity is categorised as acute, subacute or chronic by duration of time since stroke occurrence, with changes in severity of stroke symptoms for the majority of cases seen within the corresponding time period. The acute phase is from stroke occurrence and lasts for thirty days ( $\pm 7$ ) with presence of the most severe symptoms (Sale et al., 2014). Then the subacute phase is seen from day thirty ( $\pm 7$ ) with reduction to swelling of brain tissues, with cessation around nine to ten weeks from stroke occurrence (Poh, 2013). During this initial period severity of symptoms is reduced with majority of sensory symptoms resolving (e.g., vision losses, speech). The chronic phase categorises six months or longer since stroke occurrence, the majority of impairments remaining affect motor function (Donoso Brown et al.). Motor impairments are the leading cause of disability following stroke (Ertelt et al., 2007). Hemiparesis of the upper limb for most stroke survivors is long-term, extenuated with neglect of the affected arm through excessive compensative use of unaffected arm in activities of daily living (Schweighofer, Han, Wolf, Arbib, & Winstein, 2009).

Function is recovered with adaptive changes from physical practice. Combining physical practice with the ability of action observation to activate brain regions as seen with action execution purely by observing actions, offers a tool to promote these adaptive changes

with half the physical practice (Cantarero et al., 2011). The brain's ability to adapt and change itself for recovery is known as neuroplasticity (Small et al., 2012).

### **Neuroplasticity**

The conception of the brain being static and there being no treatment for injury to the brain is a notion of the past. The emergence of neuroplasticity has led to intensive exploration for recovery methods across the scope of brain injuries, including stroke recovery (Murphy & Corbett, 2009). Recovery after stroke is attainable through neuroplasticity whether damage to motor network is partial or the full motor system is damaged (Bhasin et al., 2012). Partial damage to motor system can be recovered through within-system reorganisation, with intact healthy tissues nearby in the same system taking up roles for the neighbouring damaged area. When all tissues within a single motor system are damaged recovery can be achieved through substitution (Buccino et al., 2006). Substitution is possible through healthy neurons ability to alter their synaptic connectivity, enabling the formation of a completely new receptive area (Small et al., 2012). Rehabilitation to promote these changes typically involves intense physical therapy with repetitive practice of active movement by the paretic limb (Lang et al., 2009).

In studies investigating adaptive neuroplasticity capacity using animal models, hundreds (>400) of movement repetitions are performed in upper extremity tasks. In humans, a specific number of repetitions required to enhance learning and recovery after stroke has not been established. This led Lang et al. (2009) to conduct an observational study to compare the volume of repetitions practiced during stroke rehabilitation methods to that seen in animal models. A range of different facilities were visited, including both inpatient and outpatient settings. Physical therapy and occupational therapy sessions were observed and a record of repetitions performed during all activities in the sessions was kept. Of those rehabilitation sessions that were aimed at recovering function of the upper extremity, Lang et al. (2009)

noted that actual practice of upper limb tasks only occurred in around half (51%) of these sessions. Results indicated the average number of repetitions with upper extremity as 32 total repetitions per session. The 32 repetitions were generally split between 2-4 different activities within the session. Lang et al. (2009) concluded that the amount of practice seen in stroke rehabilitation is very low compared to animal models and suggests current volumes as inadequate to promote use-dependant neuroplasticity. Studies investigating the amount of practice required to optimise use-dependant neuroplasticity in stroke rehabilitation are needed.

### **The Healthy Brain and the Stroke Brain**

Recently, Garrison, Aziz-Zadeh, Wong, Liew, and Winstein (2013) conducted an experiment to understand cortical activity during action observation in the stroke brain, compared to the healthy brain. Twenty four right hand dominant participants were recruited; twelve healthy individuals were matched to twelve stroke survivors with previously dominant right hand affected by left hemisphere. Cortical activity in motor areas was measured using fMRI during action observation of functional tasks performed by left and right hands. Participants observed functional tasks included lifting a pencil, stacking checkers while undergoing fMRI scan, and thereafter, all participants performed the same task. In both the healthy and the stroke brain greater activation of motor areas was seen in the hemisphere corresponding to the hand with the lowest motor score, non-dominant left hand in healthy and hemiparetic right hand in stroke survivors. In the healthy participants activation was seen in both hemispheres during observation of functional tasks performed by the left and right hand. Whereas the stroke participants demonstrated bilateral activation of motor areas during left hand observation only, while activation during right hand action observation was lateralised to motor areas of the left hemisphere. These results demonstrate variations in activation of the 'healthy' brain versus the stroke brain. In those stroke participants where areas of the mirror

neuron system are lesioned, cortical activation during action observation was seen in adjacent intact tissues. This finding is suggestive of adaptive neuroplasticity, advocating the use of action observation and imitation after stroke (Garrison et al., 2013).

A main premise for stroke rehabilitation is to encourage neuroplasticity; with greater recovery associated with neural reorganisation in the lesioned hemisphere. Garrison et al. (2013) findings confirm that action observation is effective in the activation of the mirror neuron system in stroke survivors, as it is in the healthy population. Therefore, it appears that an observation-execution matching system coupling perception and action exists through the mirror neuron system that may be targeted through action observation training.

### **Action Observation with Physical Practice for Upper Limb Recovery after Stroke**

Few studies have investigated the value of action observation for upper limb rehabilitation in stroke with the addition of physical practice of the observed motor skills. The findings of these studies are not consistent across the examination of action observation with physical practice in acute and chronic stroke. A prevalent method used for delivering action observation is use of pre-recorded video footage of actions. The following studies exploring action observation with physical practice for rehabilitation of stroke affected hemiparetic arm use video footage.

Ertelt et al. (2007) conducted the first experiment to examine the use of action observation with physical practice for improving function of the hemiparetic arm and hand in chronic stroke. Thirteen participants with moderate functional impairments in hemiparetic arm and hand were recruited and randomised into the control group ( $n = 6$ ) and experimental ( $n = 7$ ) group. Outcomes were measured using fMRI to evaluate activation of motor areas while participants manipulated small objects, along with functional test measures. Function of participants' hemiparetic arm and hand was assessed with standard test measures; the Wolf Motor Function Test and the Frenchay Arm Test. The Wolf Motor Function Test assesses

motor function of participant's hemiparetic arm in functional tasks, with time recorded for task completion. The Frenchay Arm Test is a measure of proximal motor control and dexterity in the hemiparetic arm and hand. The experimental group underwent action observation training, watching video sequence containing arm and hand movements for 6 minutes, followed by repetitive practice of the observed actions for another 6 minutes. The control group participants also watched a video sequence for 6 minutes. The video footage shown to the participants of the control group contained images of geometric shapes and letters. After viewing images of geometric shapes the control group performed 6 minutes of repetitive physical practice, performing the same arm and hand movements as the experimental group. In the control group, participants performed arm and hand movements using verbal instructions given by a therapist. Results indicated a significant increase in activation of the mirror neuron system in the experimental group compared to the control group. Significant difference in functional test measures Wolf Motor Function Test and the Frenchay Arm Test indicating improvement to function of hemiparetic arm and hand was shown for the action observation group, but not for the control group. The authors concluded that action observation training combined with intensive repetitive practice of observed actions is beneficial in chronic stroke for rehabilitation of upper limb impairment as seen with significant improvements to motor function. In combining use of brain imaging measures and functional test measures, Ertelt et al. (2007) provides neural level evidence as well as behavioural level evidence for action observation training and the role of mirror neurons. The combination of neural and behavioural level evidence, justifies the use of action observation for accessing the mirror neuron system in behavioural studies.

Celnik, Webster, Glasser, and Cohen (2008) examined the use of action observation with concurrent physical practice of thumb movements in chronic stroke. Action observation with simultaneous physical practice of thumb movements was performed in two of the

sessions. The action observation sessions with simultaneous physical practice involved congruent practice in the same direction as those observed and incongruent with simultaneous performance of thumb movements in the opposite direction. These were compared to a control session of physical practice alone. Eight chronic stroke survivors were recruited and participated in all three intervention testing conditions separated from other sessions by at least seven days, in a crossover design. Transcranial Magnetic Stimulation (TMS) was used to evoke thumb movements for establishing baseline measure used to set training target for thumb movement performance. TMS uses a magnetic coil which is connected to a high-voltage discharge system enabling magnetic field changes. The magnetic coil is placed on the head over the region of brain tissue that will be targeted. Changes to the magnetic field induces an electrical current, which in turn depolarises neural axons evoking movement potentials (Groppa et al., 2012). Electromyography measures of the involved muscles were recorded for evaluating activity of MEP during the sessions. In the physical practice alone session participants performed thumb movements in opposite direction to those evoked with TMS at baseline. In the action observation session congruent session, participants performed thumb movements in time with the video demonstration in the same direction as observed on the video. Participants also observed video demonstrations of thumb movements during the action observation incongruent session, again participants performed thumb movements simultaneously with the video but thumb movements were performed in the opposite direction to those observed. Results indicated an increase in the percentage of thumb movements performed within the training target zone for the action observation congruent session, but did not increase in the action observation incongruent or physical practice alone sessions. Significant increase in MEP activity was seen with action observation congruent but not in the other sessions. However, a slight change was indicated in the action observation incongruent session, with a decrease in MEP activity with physical practice alone. The



authors concluded that action observation with concurrent physical practice performed in the same direction as the observed action can heighten benefits to motor learning. Furthermore, Celnik et al. (2008) supports action observation use for improving motor recovery in chronic stroke. The authors concluding statements indicate that concurrent quality of physical practice and the action observation is highlighted in the reported benefits of action observation performed in the same direction. However, in all of the testing sessions physical practice was performed simultaneously with action observation. Celnik et al. (2008) could have halved their sample of participants into simultaneous physical practice and physical practice following observation. Future investigations comparing action observation with concurrent physical practice and action observation with physical practice following observation would be of interest.

Lee, Roh, Park, Lee, and Han (2013) focussed on a single drinking task in examination of action observation with physical practice. Action observation with physical practice was compared to a control group and groups performing action observation and physical practice in isolation of each other. Thirty three right side hemiparetic chronic stroke survivors were recruited and randomised into one of four groups, control group ( $n = 7$ ), action observation with physical practice experimental group ( $n = 9$ ), action observation without physical practice experimental group ( $n = 8$ ) and physical practice without action observation experimental group ( $n = 9$ ). Outcome measure assessed a drinking task, evaluating the number of repetitions participants performed in one minute. The score achieved on outcome measure was calculated as the number of repetitions performed with demonstration of all components of the drinking sequence. The drinking task sequence involved three components, the right hand reaching towards the cup to pick it up, then bringing the cup to the mouth and finally returning the cup to its initial position. Action observation video footage showed a right hand performing the full drinking task sequence.

Session duration for the three experimental groups was 10 minutes. The action observation with physical practice experimental group watched the video footage of the drinking task for five minutes, viewing the action repetitively before then performing the task during five minutes of physical practice. The action observation without physical practice group viewed video footage of the drinking task continuously for the 10 minutes, during this time the group was required to imagine themselves performing the task. The physical practice without action observation group viewed no video footage and repetitively performed the drinking task as per verbal instruction from a therapist for 10 minutes. The control group was not shown any video footage nor did they practice any tasks, the only interaction from the control group was assessment of task performance for outcome measure. Results indicated significant improvements in the three experimental groups compared to the control group. The largest score improvement from baseline to post-test was seen in the action observation with physical practice group, with average number of repetitions increasing by nine from 16.1 to 25.1. Baseline to post-test scores for action observation without physical practice and physical practice without action observation groups increased by five and seven repetitions, respectively, while a decrease in repetitions was seen in the control group. The authors recognised action observation with physical practice as the most effective of the techniques examined and its value in promoting activation of the mirror neuron system. Again, action observation with physical practice proved valuable in findings presented by Lee et al. (2013). Although, inclusion of a standard functional assessment used in stroke such as the Wolf Motor Function Test or the Fugl-Meyer Assessment would have been beneficial to complement the outcome measure generated by Lee et al. (2013). Addition of a standard functional assessment that is not directly related to the only task trained would have allowed for determination of whether improvement to hemiparetic arm would be transferred to many daily functional tasks or be isolated to the practiced drinking task.

Franceschini et al. (2012) conducted a similar study in acute stroke, with a sample of participants 30 days post-stroke. Also delivering action observation via video footage, Franceschini et al. (2012) examined the use of action observation with physical practice as an additional treatment to compliment standard rehabilitation of upper limb function. Standard rehabilitation involved physiotherapy for both the upper and lower limb, including tasks for arm and hand as well as gait training and individually tailored exercises. Functional tests; the Box and Block Test, the Fugl-Meyer Assessment (FMA) and the Frenchay Arm Test were used to assess hemiparetic arm motor function from baseline to post-test. The Box and Block Test assesses gross grasp evaluating the number of blocks a participant can transfer one at a time from one side of a box to the other in one minute. The FMA examines sensorimotor function of the hemiparetic arm and hand with assessment of reflex activity, movement patterns and involvement of synergy, coordination and speed (Sullivan et al., 2011). Seventy nine participants were recruited and randomised to either the control group ( $n = 39$ ) or the experimental group ( $n = 40$ ). The experimental group viewed video footage of goal and object directed daily routine tasks being performed by another individual. This video footage was viewed for three minutes and then the participant was given two minutes to imitate the movement. The control group in place of action observation training was shown video footage containing random images. As with the experimental group, video footage ran for three minutes and then the participants were given two minutes to move and perform limb movements guided by verbal instruction from a therapist in terms of directions and angles. The limb movements performed by the control group did not incorporate object manipulation, nor were movement goals given. Both the experimental and control groups completed two, fifteen minute sessions per day along with standard physical therapy, for twenty consecutive working days. A new task was delivered per day of the intervention, with tasks progressing in level of difficulty over the 20 sessions. Results demonstrated

improvement in all functional test measures for both the control and the experimental groups. Between group differences indicated significantly higher post-test score on the Box and Block Test in the experimental group compared to the control group. No additional benefits were noted when participants were followed up 4-5 months after the completion of the intervention. The authors advocate the use of action observation as a rehabilitation tool for recovery of hemiparetic arm function after stroke.

Action observation is not delivered solely by viewing video footage, in-person demonstration of actions can be observed. An example of this is study by Cowles et al. (2012) which examined the effectiveness of action observation as performed by a therapist sitting alongside participants. Action observation with intent to imitate during physical practice was compared to conventional physical therapy for upper limb rehabilitation in acute stroke. Conventional physical therapy employed included a mixture of active and passive assisted movement and unilateral reaching activities using the hemiparetic arm, along with bilateral functional activities. Twenty two stroke survivors between three to 31 days post-stroke were randomised to either the experimental group completing action observation in addition to conventional physical therapy ( $n = 9$ ) or the conventional physical therapy control group ( $n = 13$ ). Function of hemiparetic arm was assessed with the Motricity Index and the Action Research Arm Test prior to receiving intervention. The Motricity Index assesses pinch grip and movement of arm in flexion and abduction of the shoulder and flexion of the elbow. Secondary measure Action Research Arm Test examines ability to perform activities of daily living with the hemiparetic arm manipulating objects of different sizes, shapes and weight. The experimental group were required to watch the therapist perform actions using the same side arm as that of the participant's hemiparetic arm for 1 to 2 minutes prior to physical practice. Participants were then given 4 to 6 minutes to imitate observed actions. Physical practice of observed action was performed in time with the therapists continued

demonstration of the action, while provided verbal correction and feedback. Results showed significant functional improvement in both the control and the experimental group as indicated with Motricity Index score changes between baseline and post-test. However, between-group difference for both the Motricity Index and the Action Research Arm Test was not significant. The authors concluded that action observation with physical practice did not add positive value to the recovery of upper limb with conventional physical practice. Cowles et al. (2012) is the only study that delivered action observation with in-person demonstrations rather than by video footage. Consequently, consistency of the in-person demonstrations made by the therapist may have been affected.

### **Summary**

The literature reviewed has provided evidence supporting the use of action observation training and the role of the mirror neuron system in motor learning. Findings of neuroplasticity potentials seen with lateralisation back towards the lesioned hemisphere are encouraging for stroke recovery (Garrison et al., 2013). As seen in the literature review, the number of studies demonstrating the potential of action observation in facilitating upper limb recovery is few. Further investigation of action observation as a rehabilitation tool for upper limb recovery in stroke is needed.

### **Rationale for the Research**

The literature review has described the immense impact of stroke; leaving many stroke survivors unable to carry out daily self-care and functional tasks (Go et al., 2012; World Health Organisation, 2011). Government programs are focussed on stroke prevention neglecting stroke recovery (Australian Institute of Health and Welfare, 2012). In particular, the need for effective rehabilitation techniques for the upper extremity is as vital as rehabilitation techniques for the lower extremity. Action observation training stands out as a practical and cost effective technique that can be easily administered at a stroke survivor's

home by the survivor independently. Therefore, as there are few studies regarding the value of action observation training, further research is required to investigate its value in recovery from stroke.

The theoretical framework for the use of action observation is neuroplasticity, common-coding and the mirror neuron system (Fadiga et al., 1995; Hecht, Vogt, & Prinz, 2001; Small et al., 2012). Through activating the mirror neuron system during observation similarly to that seen during action execution (linked to common-coding theory), motor representation may be stimulated to reactivate or reorganise (plasticity) neural connections (or pathways) of the motor control system (Buccino et al., 2006). The neural and behavioural evidence presented in the literature review support this theoretical framework, which formed the theoretical basis for this honours project. However, there appears to be limitations in the existing literature on action observation training that appear to not take full advantage of the predictions of the theoretical framework. For example, the delay between action observation and imitation is quite large, with up to 6 minutes reported in the literature (see Ertelt et al., 2007; Lee et al., 2013). Thereafter, 6 minutes of imitation in terms of physical practice is provided, with no immediate priming of the motor system. In this honours project action observation of each functional task lasted for around 20-30 seconds and was immediately followed by physical practice of the observed functional task for 30 seconds. In relation to this, the mirror neuron system has been shown to be active from observation of an action until the action is executed or new movement pattern is perceived (Buccino et al., 2006). Hence, it was anticipated that immediate imitation will heighten motor system priming for physical practice.

The low volume of repetitions is another potential limitation during rehabilitation tasks that needs to be considered in relation to the theoretical basis of neuroplasticity. The use of hundreds of movement repetitions (>400) have been reported to be important in animal

models for cortical reorganisation (Lang et al., 2009). No such figures have been seen in stroke rehabilitation as reported by Lang et al. (2009). This honours project increased the number of repetitions towards those reported in animal models. During the sessions of action observation training in this honours project, an average of 177 movement repetitions were performed per session. This is a substantial increase from the average of 32 movement repetitions per sessions reported by Lang et al. (2009). In addition, unlike the inconsistencies in previous action observation studies into stroke, the volume of physical practice was kept constant across both the control and action observation phases in this honours project, which allowed the additive value of action observation over physical practice to be determined. The influence of motor expertise on the mirror neuron system found by Calvo-Merino et al. (2005) supports the use physical practice of functional motor skills that are used in everyday life, along with action observation for improving motor function of hemiparetic arm in stroke. Larger increases in MEP reported by Fadiga et al. (1995) with observation of actions involving an object compared to without the object suggests the importance of object manipulation with action observation. The action observation video images viewed during the experiment was shown from first person perspective, as shown to be effective in studies by Ertelt et al. (2007) and Franceschini et al. (2012).

The purpose of this honours project was to examine whether action observation training with immediate opportunity for physical practice, improves upper limb motor skill function in chronic stroke survivors. The research questions that will be examined in this thesis are: (a) will a greater increase in improvement in functional test measure scores be seen following intervention phase (post-test 1 → post-test 2) compared to following the control phase (pre-test → post-test 1), (b) will self-efficacy measures reflect actual functional improvements.

### CHAPTER 3

#### Abstract

The effectiveness of action observation training with immediate physical practice for improving function of the hemiparetic upper limb in chronic stroke was examined in a within-subject time series design. Fourteen stroke survivors at least 6 months post stroke occurrence acted as their own controls, completing a relaxation sham phase to introduce intensive, repetitive physical practice and establish baseline before the introduction of action observation training. Action observation training sessions included five motor skills to be viewed with intent to imitate and subsequently practiced for 30 trials each (10 sets of 3 repetitions). Action observation training video sequence duration was kept to a minimum with participants viewing the motor skills for 30 seconds and then immediately practicing the observed motor skill. Primary outcome measures including the Fugl-Meyer Assessment (FMA) and the Functional Test of the Hemiparetic Upper Extremity (FTHUE) were used to characterize the level of motor function of the hemiparetic arm and hand. Secondary outcome measures included participant perception of functionality of the impaired arm using questionnaires and a structured interview. Improvement on functional and self-perceived measures over the time series was found in both the control and action observation training phases. Changes in primary outcome measures were greater during the action observation training phase. The findings of this study indicate that action observation training can be valuable as a rehabilitation tool for short-term functional benefits of the hemiparetic upper limb in chronic stroke. More robust experimental work is needed that uses a randomised control trial design and tests the durability of the benefit.

*Keywords:* stroke, rehabilitation, hemiparesis, mirror neuron system, action observation, upper limb.



## Does Action Observation Training with Immediate Physical Practice Improve Hemiparetic Upper Limb Function in Chronic Stroke?

Observation of human actions has been reported to activate similar brain regions that are active when these actions are overtly executed (Buccino et al., 2004; Fadiga et al., 1995). This network of neurons is known as the mirror neuron system (Iacoboni & Mazziotta, 2007; Small et al., 2012). When an action is observed, however, with the intention to imitate the observed action, there is maximal activation of the mirror neuron network (Caspers, Zilles, Laird, & Eickhoff, 2010). This neural level relationship between observation of action and action execution is also explained by the common-coding hypothesis at the behavioural level, where training perception can contribute to an action task and training action can contribute to a perception task (Calvo-Merino et al., 2005; Hecht et al., 2001). Accordingly, it has been reported that motor skills that are usually learnt with repetitive task-specific practice can be improved with observation of the motor skill alone (Cantarero et al., 2011; Cross et al., 2009).

The capability of action observation to prime the motor system through the mirror neuron network provides a mechanism for promoting neuroplasticity and improvement in motor function in stroke that would otherwise be limited to use-dependant interventions (Cantarero et al., 2011; Lang et al., 2009). Recovery of function after stroke facilitated by activation of the mirror neuron system has been attributed to reorganisation within damaged areas, formation of new receptive fields as well as cortical remapping and substitution with healthy tissues taking up functions of damaged areas (Bhasin et al., 2012; Murphy & Corbett, 2009; Small et al., 2012). A recent fMRI study by Garrison et al. (2013) compared neural activation in healthy age-matched individuals and left hemisphere stroke brains of right-handed participants during action observation. Results revealed greater activation of the mirror neuron network in the left lesioned hemisphere of stroke survivors during observation

of paretic limb (right-handed) actions, than for healthy controls. Results also showed that damage to regions of the mirror neuron network were compensated by activation of adjacent brain regions. These important findings suggest that action observation (perception) and motor execution (action) regions in the chronic stroke brain are linked with perception-action coupling maintained after trauma. Collectively, a theoretical basis exists for action observation training based upon the linkage between perception and action through the induction of neuroplasticity.

Evidence on the effectiveness of action observation as a tool for stroke rehabilitation is equivocal. Only five studies have examined the use of action observation with physical practice for upper limb recovery after stroke; four examining chronic stroke and one acute (Celnik et al., 2008; Cowles et al., 2012; Ertelt et al., 2007; Franceschini et al., 2012; Lee et al., 2013). These studies examined the use of action observation with physical practice compared to conventional physical therapy control group (Cowles et al., 2012), control group viewing random images and geometric shapes in place of action observation (Ertelt et al., 2007; Franceschini et al., 2012), a control group completing no intervention (Lee et al., 2013) and physical practice alone (Celnik et al., 2008). Findings of these studies vary with Cowles et al. (2012) reporting no significant difference between action observation group and the conventional physical therapy control group in acute stroke, whilst the other studies report significant improvement in motor function after action observation with physical practice compared to the control.

There are several methodological features of the foregoing action observation studies that need to be considered when determining the value of their interventions. First, in previous studies, the duration of action observation ranges from 1-2 minutes up to 6 minutes followed by physical practice for 2 to 6 minutes, except for Celnik et al. (2008) where participants practiced actions simultaneously while observing video of actions. Evidence

indicates, however, that once the mirror neuron system is primed through observation of an action it remains activated until the end of the performance sequence of the executed action (Buccino et al., 2006). Therefore, if the purpose of action observation is to prime the motor system via the mirror neuron system, then it follows that observation and opportunity for physical practice need to be more closely connected in time to take maximum advantage of the priming effect. Behavioural evidence of immediate priming of the mirror neuron system and the benefits to functional tasks in chronic stroke are lacking. Second, previous studies have not consistently included a physical practice control condition; hence, it is not possible to determine the additive benefit of action observation coupled with physical practice to any improvement in functional tasks. Third, previous studies have used functional tests with a smaller range of functional motor skill. Fourth, there is scarce evidence of the interplay between improvement in functional measures and perceived benefits to motor function in chronic stroke survivors from action observation training (Ertelt et al., 2007; Franceschini et al., 2012).

This experiment aimed to add to the limited literature on the effectiveness of action observation in chronic stroke. In particular, unlike previous studies, the purpose of this within-subject study was to include a unique element of interleaved action observation with physical practice soon after observation of each single motor skill. Using recent fMRI evidence of mirror neuron system activation in chronic stroke (e.g., Garrison et al., 2013), as well as available behavioural evidence, the first hypothesis was that chronic stroke survivors will exhibit a greater improvement in upper limb functional measures following the action observation training phase compared to a practice-only control phase. The secondary hypothesis pertains to improvement of patient self-perceptions of perceived benefits to motor function from the action observation training (Boake et al., 2007).

## **Method**

## Participants

A convenience sample of participants was recruited from the Australian National Stroke Foundation facilitated stroke support groups held in Perth suburbs (see Figure 1).

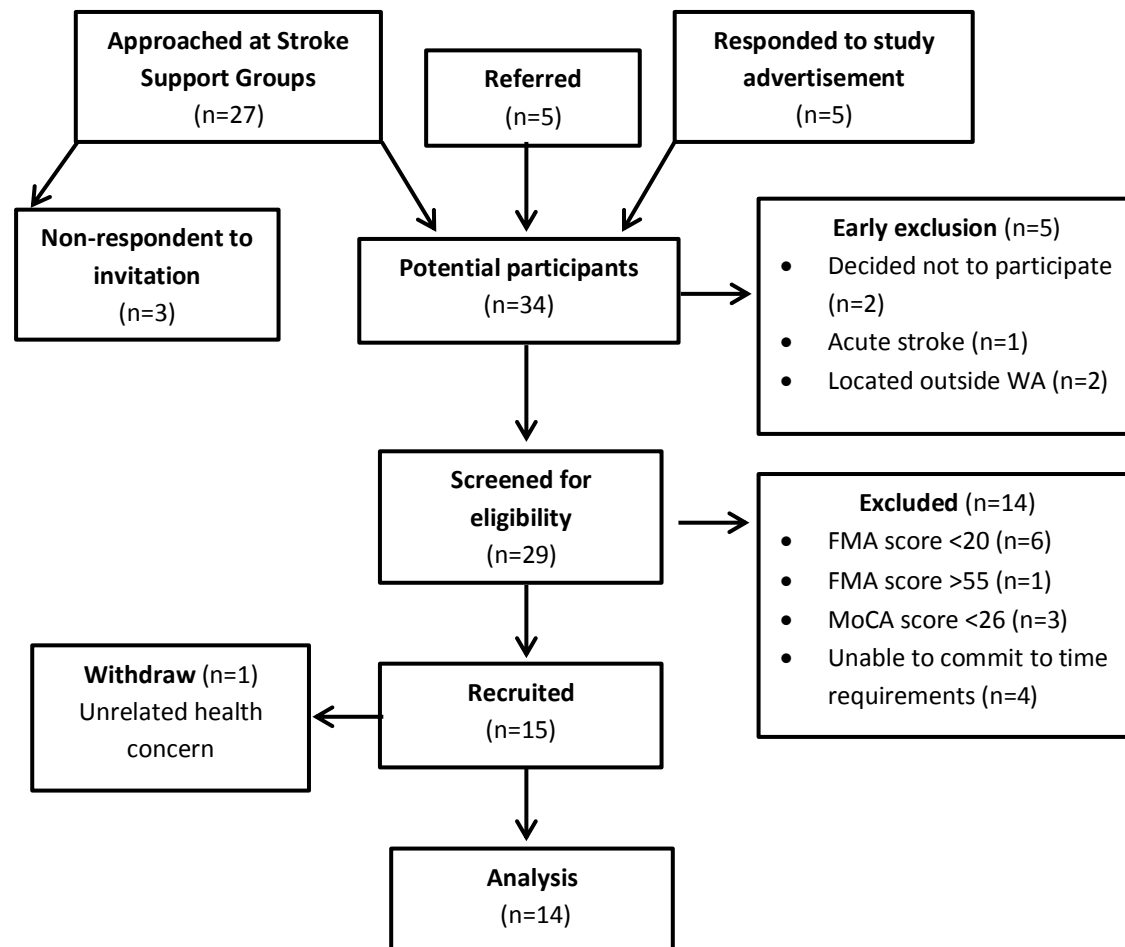


Figure 1. Consort diagram presenting participant flow from sampling to data analysis. Parentheses indicate number of sample in each process. FMA = Fugl-Meyer Assessment, MoCA = Montreal Cognitive Assessment.

Fourteen chronic stroke survivors (greater than six month stroke duration) meeting the inclusion criteria were enrolled into the experiment<sup>1</sup>. Inclusion criteria included those: (a) at

<sup>1</sup> Sample size was projected based on changes in functional test scores Ertelt et al. (2007). G-power statistical analysis software was used to estimate sample size required. Using an effect size of .85, alpha .05 and power 80%, analysis indicated a sample size of at least 10 participants.

least 18 years of age and with no upper limit on age, (b) not enrolled in a hospital in-patient rehabilitation program at time of experiment, (c) that had some movement in the paretic upper limb (i.e., FMA, score between 20 and 55), (d) that scored 26 out of 30 on the Montreal Cognitive Assessment (MoCA) and were able to communicate effectively for completion of testing and intervention sessions, as well as (e) able to commit to time requirements of the study. Exclusion criteria included not meeting the above inclusion criteria and those with spatial neglect, as indicated in visuospatial section of MoCA (impairment to the visual field). Demographic restriction was applied to ensure selected participants were located within 60kms of Murdoch University's South Street Campus. Table 1 provides details of participant demographics. The experiment was approved by Murdoch University Human Research Ethics Committee and registered on the Australian New Zealand Clinical Trials Registry—ACTRN12313000937718. All participants gave written informed consent.

### **Research Design**

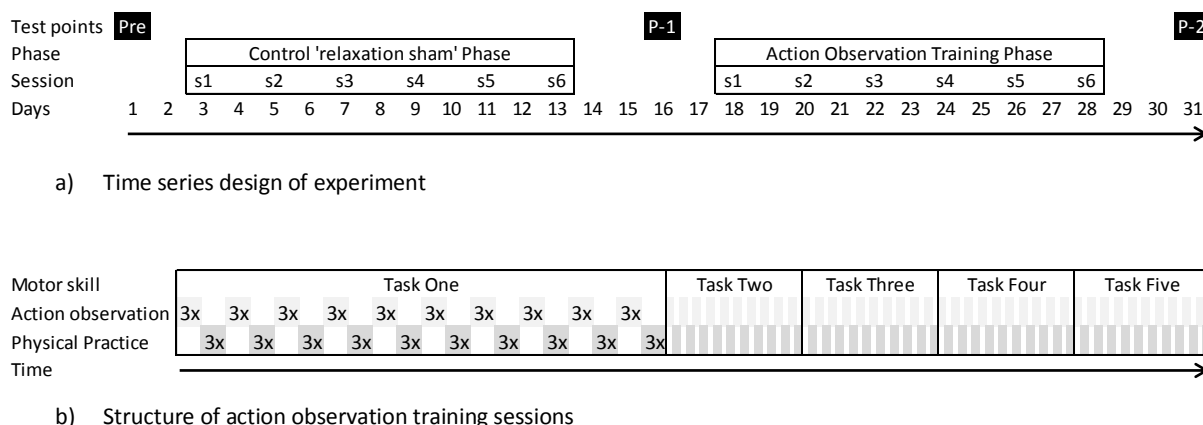
This experiment consisted of a within-subject time series design where participants were their own controls. Figure 2 demonstrates testing points and phases of the time series design. A pre-test was followed by phase 1 'relaxation sham', identical to phase 2 in all aspects except video footage shown consisted of random environmental scenery prior to the opportunity for physical practice of selected motor skills. The purpose of phase 1 was to establish a baseline contribution of physical practice alone to the pre- to post-test 1 change of relevant test measures. Action observation training intervention was then delivered in phase 2 followed by final test point, post-test 2. There was no break between the end of phase 1 and the beginning of phase 2. Action observation training included participants watching video footage of selected motor skills followed by physical practice of the same observed motor skill. The purpose of phase 2 was to determine the priming value of action observation prior to physical practice by comparing post-tests 1 and 2.

Table 1.

*Demographics: Participants with chronic stroke, characteristics and values at time of recruitment*

Participant	Age (years)	Sex	Dominant side	Type of Stroke	Side of lesion	Location of lesion	Time from onset (years)	Screening test scores		Sociological characteristic		
								FMA	MoCA	Education (ISCED)	Marital status	Living arrangements
1	63	F	R	CI	LH	PTO	16.9	39	26	≥4	De facto	HS
2	69	F	R	CI	LH	Thalamus	2.5	49	30	≥4	Married	HS
3	61	F	R	ICH	LH	FL	10.2	23	26	<4	Married	HSD
4	61	M	R	CI	LH	PL	2.7	41	29	≥4	Married	HS
5	74	M	R	ICH	LH	Basal Ganglia	6.6	37	26	≥4	Divorced	HA
6	78	M	R	ICH	RH	Subcortical	4.6	32	27	<4	Married	HS
7	76	F	R	CI	RH	PL	2.4	22	27	<4	Divorced	HA
8	62	F	R	CI	LH	Thalamus	2.6	36	28	≥4	Married	HS
9	74	M	R	ICH	LH	IPL	1.8	36	26	<4	Married	HS
10	69	M	R	CI	RH	IPL + STG	2.4	35	27	≥4	Married	HS
11	73	F	R	ICH	RH	Subcortical	15.6	20	29	≥4	Married	HS
12	69	M	R	CI	RH	PTO	1.3	26	27	≥4	Married	HS
13	73	M	R	CI	RH	PL	11.6	21	26	≥4	Married	HS
14	62	F	R	CI	LH	PL	41.5	45	30	<4	Married	HSD
Mean (SD)/f	68.86 (6.04)	7M/ 7F	14R	9CI/ 5ICH	8L/6R		8.76 (10.80)	33 (9.29)	27.43 (1.50)			

*Note.* FMA = Fugl-Meyer Assessment upper extremity section, MoCA = Montreal Cognitive Assessment; SD = Standard deviation, f = frequency; F= female, M = male; L = Left, R = Right; CI = Cerebral infarction; ICH = Intracerebral Haemorrhage; LH= Left Hemisphere, RH= Right Hemisphere; PTO = Parietal-Temporal-Occipital association area, FL = Frontal Lobe, PL = Parietal Lobe, IPL = Inferior Parietal Lobe, STG = Superior Temporal Gyrus. Living arrangement codes: H = living in own home; S = with spouse, A = alone, D = dependents living at home. ISCED (International Standard Classification of Education), 4 = full secondary education (senior year).

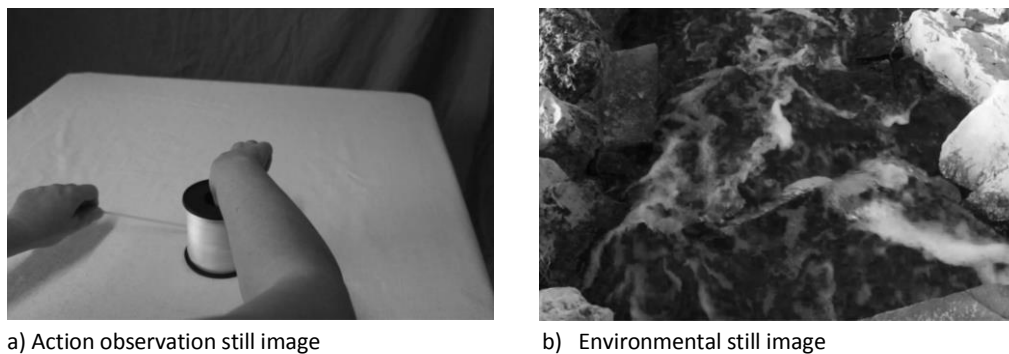


**Figure 2.** Timeline diagrams of a) time series design of experiment and b) structure of individual Action Observation training sessions. a) Pre = pre-test, P-1 = post-test 1, P-2 = post-test 2, s = session; progression of timeline in days as indicated by arrow. b) Average time of individual video clip is 11 seconds; this is shown 3 times consecutively followed by physical practice of the motor skill for 3 attempts. This process of observation and immediate physical practice is repeated 10 times. Tasks two to five are as per task one, but have been compressed. Session time varied between one hour and 90 minutes with influence of individual participant level of function and motor skill complexity.

## Procedure

The duration of the study was five weeks, consisting of three testing points (baseline, Post 1, Post 2) and six training sessions (3x/week for two weeks) in each of the two phases. Fugl-Meyer Assessment (FMA), Functional Test of the Hemiparetic Upper Extremity (FHTUE) and the Confidence in Arm and Hand Movement Scale (CAHM) measures were collected at each of the test points. In addition to these measures the Motor Activity Log (MAL) and a structured interview were conducted at each post-test. Following baseline, training sessions were delivered on alternate days, then post-test 1 (phase 1), followed by action observation training with physical practice, then post-test 2 (phase 2). Testing and training phases were delivered by the same single assessor, an Accredited Exercise Physiologist (qualified allied health professional). Training sessions were conducted in participants' homes at the same table used in testing, standard height of 28 inches from ground to table top. The table was set up in available open area in living or dining room, all possible distractions were removed and sources of noise eliminated. Participants were seated

at the table with 15.5 inch laptop computer screen for viewing video footage positioned 18 inches in front of them. Training sessions lasted between an hour and 90 minutes depending on task difficulty and participant capability, with five motor skill tasks practiced each session. The main feature of the video footage specific to either phase 1 or 2 was the interleaved quality with environmental scenery or action observation (see Figure 3 for still image examples of each) followed soon after by physical practice of the motor skill.



*Figure 3.* Still image of action observation footage is seen in image a) demonstrating view point of motor skills shown to right side hemiparetic participants. In this motor skill the participant uses their hemiparetic arm to stabilise and maintain position of ribbon spindle against torque created by their unaffected hand pulling ribbon from the spool. Still image of environmental footage shown during relaxation sham (phase 1) b). A variety of environmental scenes including natural and man-made water sources, flora, broad landscapes and clouds were shown during relaxation sham.

Motor skills delivered in each phase were selected from one of two lists (list A or B) designed to be equivalent on all levels. The selection of motor skill lists for participants was counterbalanced, with half of the participants completing list A in phase 1, then list B in phase 2 and the other half completing list B in phase 1 and then list A in phase 2. Sessions were structured to provide 10 opportunities to attempt three repetitions of each of the five motor skills. This session structure allowed for an increased volume of practice, with higher volumes of practice associated with neuroplasticity (Lang et al., 2009). The average number of repetitions of physical practice participants completed per session was equal for the control



and action observation phases ( $177 \pm 24$  SD), ranging between 147 and 300 for the 14 participants.

**Phase 1: Relaxation sham plus physical practice.** Participants watched approximately 30 seconds of video footage of environmental scenery before physical practice of motor skills selected by Exercise Physiologist delivering interventions (see Figure 2). Participants were informed that the intention of the environmental footage was to relax them prior to physical practice. These instructions were given in an attempt to ensure the participants engaged with the sequences of watching random video images prior to physical practice. Verbal instruction and cues that were established for each motor skill were given pertaining to the goal of motor skill, movement direction and sequence to guide participants during physical practice.

**Phase 2: Action observation plus physical practice.** Participants watched video clips of a healthy individual performing motor skills (e.g., stirring a cup). Video clips were filmed from over an actor's shoulder for point of view of a person looking down at their own arm (see Figure 3). Video clips were shown to participants as either the left or right hand depending on participant's hemiparetic side. Video clips of the same motor skill were shown three times consecutively in place of the 30 seconds of environmental footage shown in phase 1 (see Figure 2). Participants were asked to watch the video footage with the knowledge that they will then attempt to mimic the same motor skill task after watching. In cases where the participant had difficulty performing the task, a series of strategies were suggested such as trying the motor skill with the unaffected side or breaking the task down into parts and using a part-practice approach involving isolation of components (e.g., if unable to grasp draw handle, start by just hooking over fingers and practicing the gross movement of pulling out draw).

## Measures

The assessor evaluated all outcome measures for each participant. Motor function was assessed with primary outcome measures FMA and the FTHUE. Secondary outcome measures CAHM scale and the MAL, as well as a structured interview gauged participants' perception of their motor function.

**Fugl-Meyer Assessment (FMA).** The FMA is a stroke specific measure of sensorimotor function (Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975; Sullivan et al., 2011). The upper extremity section of the FMA scores motor function between 0 and 66 with assessment of reflex activity, movement patterns and involvement of synergy, coordination and speed. FMA items are graded between 0-2, level of motor function corresponds to score achieved with higher scores indicating more function. The assessor was trained in use of the FMA by a physiotherapist. Training in FMA use involved assessment of stroke and multiple sclerosis patients not participating in the study over four sessions, within a two week period. Inter-rater reliability was determined with comparison of a tested participants FMA scores for test 1 and test 2 (separated by six weeks) pre and post their participation as rated by the assessor to that of the physiotherapist, with 100% agreement. Spot checks of participants FMA scores throughout the study saw inter-rater agreement maintained at 100%.

**Functional Test of the Hemiparetic Upper Extremity (FTHUE).** The FTHUE measures motor function with examination of ability to achieve functional tasks with the hemiparetic upper extremity (Wilson, Baker, & Craddock, 1984; Winstein et al., 2004). Seventeen functional tasks are used across 7 levels increasing in difficulty with higher levels. Starting at level 1 with no voluntary movement of shoulder, elbow or hand, levels increase with minimum motion requirements. Minimal motion requirement is voluntary motion of shoulder and elbow, gradual improvement to mass flexion patterns at these joints are seen across levels with addition of gross grasp, elbow extension and lateral pinch. Movements

combining flexion and extension patterns are then expected with increases in strength and weight of grasps and some ability to release objects. In final levels isolated control in shoulder, elbow and wrist against gravity, with full extension of these joints and in fingers needs to be demonstrated in tasks combined with good coordination and control. With exception of the first task, time to task completion is recorded for each of the seventeen tasks with a maximum of three minutes allowed for each or three attempts, whichever is first. The performance of each functional task is graded plus or minus with completion. To be graded plus the hemiparetic hand must assist functionally and not interfere in reaching the task goal. Level is awarded as the highest level in which all tasks within the level are achieved as graded as a plus.

Video footage was captured during FTHUE assessment using a standard video camera perpendicular to the participant's hemiparetic side. Captured video footage allowed for multiple observations of the collected FTHUE data for determining inter- and intra- rater reliability. A second rater viewed collected video footage and recorded time to task completion, graded completed tasks and level achieved for each participant. Inter-rater reliability of tasks and level achieved showed 100% agreement, time averages for the FTHUE was determined using Inter Class Correlation (ICC) model 2 according to Portney and Watkins (2009). All test time points exhibited excellent inter-rater reliability, pre-test; ICC= 0.998, post-1; ICC= 0.973 and post-test 2; ICC= 0.991. The experiment's single assessor (first rater) viewed collected FTHUE video footage of and performed a second evaluation. Intra-rater reliability of time averages for the FTHUE was determined using Inter Class Correlation model 3 according to Portney and Watkins (2009). Intra-rater reliability of tasks and level achieved indicated 100% agreement, all test time points exhibited excellent intra-rater reliability of FTHUE time averages, pre-test; ICC= 0.943, post-test 1; ICC= 0.987 and post-test 2; ICC= 0.981.

**Confidence in Arm and Hand Movement (CAHM) scale.** The CAHM scale is a self-efficacy questionnaire in which participants give a rating out of 100 percent indicating confidence in ability to use their hemiparetic arm and hand for tasks listed (Chen, Lewthwaite, Schweighofer, & Winstein, 2013). A rating of 100 percent indicates that the participant is very certain they can use their hemiparetic arm and hand for the task if attempted, with 0 percent on the other end of the scale as very uncertain they could do the task and reluctance to attempt the task. The CAHM questionnaire delivered in this study is adapted from the original 20 item CAHM, employing the 0-100 confidence scale based upon the functional tasks of the FTHUE.

**Motor Activity Log (MAL).** The MAL uses a rating scale to gauge participant's reflections on the use of their hemiparetic arm for functional activities at home (Uswatte, Taub, Morris, Light, & Thompson, 2006). Participants are asked to recall use of their hemiparetic arm in 28 items of functional activities around the home over the previous two days. In those items that the hemiparetic arm was used, participants indicate a 'how well' rating between 0 and 5 of how well the activity was performed. A rating of 0 indicates that the hemiparetic arm was not used at all for that activity and 5 indicates the ability to use the hemiparetic arm for that activity was as good as before the stroke.

**Structured interview question.** Based upon an open-ended question "how do you feel about the value of the training completed over the last two weeks for improving the function of your affected arm?" interviews were structured with selection of follow up questions depending on participant's response (Madill, 2011). At the completion of the study participants were also asked whether they had preferred or found either the environmental footage or the videos demonstrating the tasks (action observation) more beneficial.

## **Data Analysis**

To determine the relative contribution of the sham-relaxation control and action-observation intervention phases to the relevant primary and secondary outcome measures, repeated measures statistical analyses were conducted. FMA and FTHUE (level and number of tasks achieved) are ordinal scale data and therefore, were analysed using Friedman's ANOVA comparing across testing points, with post-hoc Wilcoxon signed ranks test and Bonferroni adjustment. FTHUE task time average ratio scale data and CAHM interval scale data were checked for normality of skewness and kurtosis between  $\pm 1.96$  (Field, 2009). Repeated measures ANOVA with post-hoc Bonferroni test was used on these measures comparing across testing points. Greenhouse-Geisser correction was applied where the assumption of sphericity was not met. CAHM data was also analysed at the item level (distribution not normal) using Friedman's ANOVA comparing across testing points to determine items that contributed to CAHM score changes. Ordinal scale MAL average rating and number of items rated were compared across post-test 1 and post-test 2 using Wilcoxon signed ranks test. Alpha level for all statistical tests was set at .05 and for relevant post-hoc comparisons a Bonferroni correction was applied that adjusted the alpha to 0.025. Qualitative data from structured interviews was analysed using thematic analysis, coding data and enabling themes to emerge (Braun & Clarke, 2006).

## **Results**

### **Primary Outcome Measures**

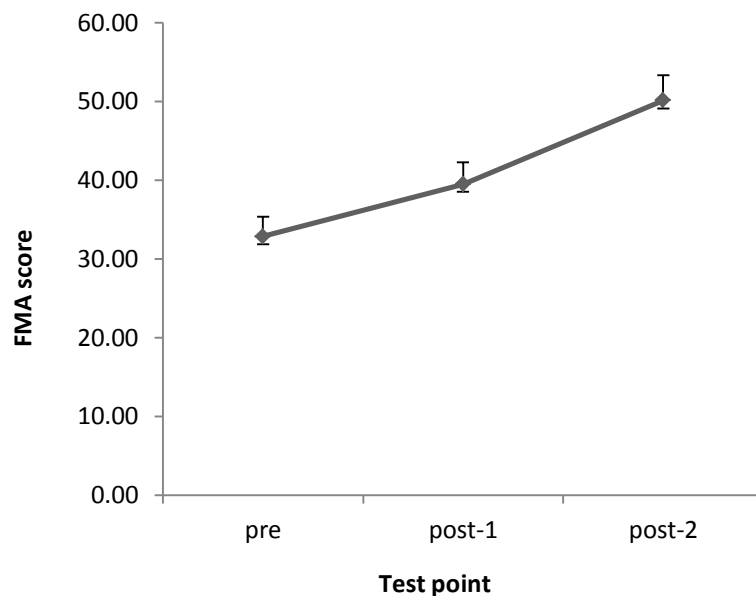
Individual participant test scores and group descriptive statistics are reported in Table 2. Friedman's ANOVA indicated a significant difference in FMA scores across time series testing points,  $\chi^2(2) = 28.000, p < 0.001$ . Post-hoc Wilcoxon signed-rank tests revealed a significant difference between pre-test to post-test 1,  $z = -3.316, p = 0.001$ , with a score increase of 6.64 points, as well as a significant difference between post-test 1 to post-test 2,  $z = -3.303, p = 0.001$ , with a larger 10.64 point increase (see Figure 4).

Table 2.

*Individual participant scores and group values for all outcome measures across time series testing points*

Participant	FMA			FTHUE									CAHM			MAL			
	Pre-	Post-1	Post- 2	Level achieved			No. of tasks achieved			Time average (s)			Pre-	Post-1	Post-2	QOM		No. items rated	
				Pre-	Post-1	Post-2	Pre-	Post-1	Post-2	Pre-	Post-1	Post-2				Post-1	Post-2	Post-1	Post-2
1	39	50	66	6	6	6	15	15	16	15.34	15.24	14.05	46.25	46.88	89.69	3.71	3.88	24	25
2	49	52	66	6	6	7	16	16	17	16.52	16.20	12.58	65.00	74.38	92.50	4.15	4.65	27	27
3	23	30	41	3	3	3	6	7	9	31.64	26.53	32.13	18.75	33.44	44.69	1.75	2.93	4	7
4	41	44	56	5	5	7	15	16	17	20.50	17.77	14.56	62.50	83.13	87.19	2.75	3.19	14	18
5	37	40	54	4	4	6	13	14	15	32.97	24.01	21.37	20.88	73.44	81.88	2.70	3.29	5	7
6	32	39	51	3	5	5	11	12	13	33.52	35.09	32.74	74.38	69.29	81.88	2.93	3.24	15	21
7	20	23	27	2	3	3	5	5	7	19.07	16.06	31.88	19.50	33.81	40.38	1.50	2.25	2	4
8	36	42	50	2	6	7	12	16	17	19.04	15.04	10.97	55.31	57.50	73.44	1.91	2.39	16	23
9	36	57	63	6	6	7	16	16	17	25.99	22.40	14.76	71.88	84.38	100.00	3.31	4.22	21	27
10	35	39	53	4	4	6	10	12	15	30.43	22.55	26.95	59.67	60.94	80.94	3.07	3.50	7	12
11	20	27	39	3	3	3	7	8	11	30.42	52.15	59.54	15.63	41.25	55.63	1.33	2.50	3	10
12	26	35	45	3	2	3	5	7	8	25.63	44.06	48.48	25.63	35.94	35.50	1.93	2.40	6	10
13	21	27	32	3	3	3	6	6	8	33.32	36.81	49.73	18.75	24.38	26.25	1.67	2.50	3	4
14	45	48	59	5	5	6	12	13	15	18.16	24.15	22.19	57.19	71.25	77.81	2.96	3.20	13	23
Mean	32.86	39.50	50.14	3.93	4.36	5.14	10.64	11.64	13.21	26.38	26.29	28.00	43.66	56.43	69.13	2.55	3.15	11.43	15.57
Range	20-49	23-57	27-66	2-6	2-6	3-7	5-16	5-16	7-17	15.34-33.52	15.04-52.15	10.97-59.54	15.63-74.38	24.38-84.38	26.25-100	1.33-4.15	2.25-4.65	2-27	4-27

*Note.* FMA = Fugl-Meyer Assessment upper extremity section (maximum score achievable = 66); FTHUE = Functional Test of the Hemiparetic Upper Extremity; (highest level achievable = 7, maximum tasks achievable = 17, time average = average of time taken over 17 FTHUE tasks (maximum time allowed to complete each task = 180 seconds); CAHM = Confidence in arm and hand movement scale; MAL = Motor Activity Log QOM = Quality of movement scale (self-perceived rating between 0-5), No. items rated = number of items on the MAL weaker arm was used in and QOM rating given (total number of items of MAL = 28); s = seconds.



*Figure 4.* Accuracy of outcome measure denoted by error bars; representing standard error values. FMA = Fugl-Meyer Assessment, score out of 66. Pre = pre-test; post-1 = post-test 1; post-2 = post-test 2.

Friedman's ANOVA indicated a significant difference in FTHUE scores across the time series testing points for level achieved and number of tasks achieved,  $\chi^2(2) = 14.387$ ,  $p = 0.001$ , and,  $\chi^2(2) = 26.235$ ,  $p < 0.001$ , respectively. Post-hoc Wilcoxon signed-rank tests indicated no significant difference in level achieved between baseline to post-test 1,  $z = -1.289$ ,  $p = 0.197$ , despite a score increase of 0.43 points. However, there was a significant increase in level achieved from post-test 1 to post-test 2,  $z = -2.598$ ,  $p = 0.009$ , with a 0.79 point increase. Post-hoc analysis also indicated a significant difference in number of tasks achieved between baseline to post-test 1,  $z = -2.754$ ,  $p = 0.006$ , with a 1 point score increase, as well as a significant difference between post-test 1 to post-test 2,  $z = -3.376$ ,  $p = 0.001$ , with a 1.57 point increase.

Repeated measures ANOVA with Greenhouse-Geisser correction revealed that FTHUE average time scores across time series testing points was not significantly different,  $F(1.384, 17.992) = 0.331$ ,  $p = 0.644$ .

## Secondary Outcome Measures

Repeated measures ANOVA indicated that mean CAHM scores differed significantly across time series testing points,  $F(2,26) = 25.72, p < 0.001$ . Post-hoc Bonferroni test indicated a significant difference between baseline to post-test 1 ( $p = 0.015$ ) and post-test 1 to post-test 2 ( $p = 0.002$ ). Mean differences of increases in CAHM score between pre-test to post-test 1 was 12.76 points and 12.70 points between post-test 1 and post-test 2. Friedman's ANOVA at the individual item level indicated significant differences across baseline to post-test 1 to post-test 2 ( $ps = 0.00-0.047$ ) for 12 of the 16 items (those relating to levels 3-6 of the FTHUE), indicating their contribution to CAHM score improvements.

Wilcoxon signed-rank test showed a significant difference in MAL scores between testing points post-test 1 and post-test 2,  $z = -3.296, p = 0.001$ , with score change of 0.60 points from 2.55 to 3.15.

Thematic analysis of structured interviews conducted during post-test 1 and post-test 2 demonstrated positive value comments such as feedback on improvements in function of their hemiparetic upper extremity and training aspects participants thought contributed to functional improvements (see Table 3 for more specific details). Whether the environmental or action observation footage was valuable, one participant felt as though they did not find a difference between the videos, whilst 13 participants reported watching video demonstrations of tasks (action observation) as more beneficial; one of which noted that they preferred watching the environmental footage although they found the action observation videos more beneficial, "I can strongly say that I improved by watching the action on the screen, immediately after it". Other statements in favour of action observation video use included "better when I can see what I have to do first" and "it's a good thing, because you see the video and you think this is what I have to do and this is how my hand should be in this position".



Table 3.

*Themes drawn from participant responses to structured interviews conducted post-test 1 and post-test 2*

Category	Thematic category	Key terms		Representative responses	
		Post-test 1	Post-test 2	Post-test 1	Post-test 2
Value	Positive	Excellent, good, rewarding, worthwhile, interesting (14)	Excellent, very good, beneficial, fabulous, thrilling, impressive, enjoyable, helpful (14)	“yeah extremely good I think” “I have found it very ah interesting”	“it’s excellent” “yeah I thought it was very good, I was quite impressed”
Feedback	Physiological	Functional improvement: ↑ use of affected arm (7) ↑ Range of motion (2) control of hand (2) improved release (1) ↑ strength and stamina (1)	Functional improvement: Movement is more automatic (4) ↑ use of affected arm (14) Faster movement (1) ↑ endurance/ stamina (1) ↑ Range of motion (1) Ability to grip (1)	“Bigger grasp” “Getting better” “Found that I can do a bit more” “Making a difference”	“I can pick things up, where I couldn’t before” “More automatic, yeah it’s a lot better” “I can lift my arm above my head”
	Psychological	Increase to awareness and concentration (3)	Increased determination, perseverance, willingness, feelings of hopefulness (4)	“it’s making me more aware of my left side”	“more willing to try it with less hesitation”
Training aspects	Training features	Repetition (6) Challenge (6) Variety and type of tasks (3) Inclusion of goal outcome (1) Discipline/ routine (1) Environmental video (1)	Action observation videos (10) Repetition (7) Variety and type of tasks (4) Challenge (4) Routine (1) Goal achievement (1) Rest between physical practice (1)	“the repetition is absolutely necessary and as you repeat a few you actually notice it gets a bit easier”	“better when I can see what I have to do first” “I found it good when it was clearly laid out on the video” “the videos were very demonstrative”
	Trainer role	Encouragement (4)	Patience, encouragement (5)	“the encouragement particularly that I have received”	“your patience and umm perseverance”

*Note.* Interviews were structured around open-ended question: “How do you feel about the value of the training completed over the last two weeks for improving the function of your affected arm?” Numbers in parentheses indicate the number of participants that mentioned the preceding key term.

## **Discussion**

This study advances our understanding of how action observation may benefit upper extremity recovery after stroke. It highlights the unique design in which action observation training was juxtaposed with physical practice soon after observation of each single motor skill. This was done in an attempt to provide more optimal activation of the mirror neuron system to prime the motor system for recovery (Buccino et al., 2006; Caspers et al., 2010). The results support the first hypothesis showing greater improvements found in the action observation training phase compared to the relaxation-sham control phase for functional measures and some perceived benefit measures.

Significant improvement in FMA scores was found in both the action observation and the control phase, however, improvements to FMA scores were greater in the action observation training phase. Improvement in FMA scores is consistent with earlier studies of action observation training when considered pre-post change scores (Franceschini et al., 2012). The action observation training phase also showed significant improvements in FTHUE level achieved, with a non-significant improvement on this measure for the sham control phase. There is no evidence in the literature of improvement in the level achieved on the FTHUE. However, Filiatrault, Arsenault, Dutil, and Bourbonnais (1991), found a strong positive correlation between the FMA and the FTHUE providing some external validity for the FMA and corresponding FTHUE improvements reported in this study. In addition, here, number of tasks achieved for the FTHUE improved significantly for both the control and action observation training phases, with greater improvements in the latter phase. Winstein et al. (2004) used the FTHUE number of tasks achieved when comparing standard stroke care and two upper extremity rehabilitation programs for stroke and found on average greater improvements in the experimental groups compared to the standard care group, but these were not significant. FTHUE time average changes showed no significant improvements

across control or action observation training phases. This could have been a product of time improvements in tasks participants can already achieve being hidden in calculation of time average as participants moved onto harder, more time consuming tasks of higher levels in subsequent testing sessions. Collectively, more immediate priming of the motor system appears to have yielded a combination of functional improvements in the intervention phase of this within-subject study.

Together with functional improvement measures, significant improvement was found in participant's perception of functional capability (self-efficacy) and actual use of the paretic arm. Significant improvement in CAHM scores across both control and action observation training phases indicates that confidence in use of the paretic arm continued to improve, but was not differentially influenced by action observation or control phases as it was for the functional measures. The CAHM has not been employed for assessing self-efficacy in stroke survivors undergoing action observation training. However Chen et al. (2013), reported a moderate positive relationship between the CAHM score and FMA score, implying that as function improves confidence in paretic arm use continues to improve, which is likely what occurred in this study. Importantly, a significant difference in MAL score after the action observation phase compared to the conclusion of the control phase, indicates that participants increased use of hemiparetic arm and hand in activities around their home. Specifically, the MAL average for the group increased from 2.55 to 3.15 following action observation training. A rating of 3 is a marker of where the affected arm was used for the activity without assistance from the unaffected arm and is an important indicator of clinical improvement (see (Wolf et al., 2010).

Structured interviews demonstrated participant favour of the action observation training phase over the relaxation sham control phase for improving function of the affected arm and hand. Participants found the action observation training videos beneficial and four

participants reported the first instances of their movements becoming automatic since stroke occurrence. This theme can be linked with functional improvement on FTHUE with action observation training contributing to achievement of high levels combining flexion and extension patterns as well as requiring increase in control of movements. Structured interviews acquiring views on hemiparetic arm recovery from stroke survivors is limited. For example, Sabini, Dijkers, and Raghavan (2013) used thematic analysis with upper limb stroke survivors and reported the theme of repetitive practice, which is consistent with reports in this study, although this study reports the additional theme of the value of action observation training.

A crucial aspect that the within-subject time series design in this study revealed was the additive value of action observation training phase to functional measures, over the practice only phase. This has important clinical significance, indicating that whilst use-dependent rehabilitation certainly is beneficial to improving function of the hemiparetic hand and arm, the implementation of action observation coupled with physical practice can yield additional benefits to improvement in hemiparetic arm function. Therefore, it appears that from a behavioural level, action observation contributes to motor re-learning in upper limb stroke survivors, which is consistent with greater activation of the mirror neuron network in the impaired hemisphere of the stroke brain (Garrison et al., 2013).

In conclusion, this study offers further favourable evidence on the effectiveness of action observation with physical practice as a rehabilitation tool for improvement in function of the upper limb and perceptions associated with these improvements in chronic stroke. Furthermore, the use of a within-subject design has revealed the additive value of action observation over and above that of task-specific practice. There appears to be potential for further investigation of the value of action observation to improve motor function after stroke that may then have clinical application in hospitals or rehabilitation clinics. Future research

requires a larger scale randomised control trial and follow-up retention test to determine the durability of the results and the value of action observation with physical practice as an intervention for promoting recovery for acute or chronic stroke.

## **CHAPTER 4**

### **Conclusions**

The purpose of the research in this thesis was to advance understanding of action observation training and how it could benefit recovery of the hemiparetic arm and hand after stroke. The duration of time between action observation and the opportunity for physical practice was considerably reduced in comparison to what was done in previous studies (e.g., Ertelt et al., 2007). This was aimed at optimising the motor system priming via the mirror neuron system (Caspers et al., 2010). In advancing our understating of action observation training for upper limb recovery in stroke, this honours thesis examined two research question: (i) effectiveness of action observation training with immediate physical practice for improving upper limb function in chronic stroke (ii) participant-perceived benefits to motor function with action observation training compared to actual functional changes. By addressing the foregoing research questions, this thesis has extended understanding of action observation in chronic stroke in three ways: (i) revealed differences to improvement seen with action observation training compared to relaxation-sham control, (ii) revealed benefits of immediate priming of the motor system to functional improvements, (iii) provided insight to self-efficacy and participants perception on the function of their hemiparetic arm and hand.

The experiment in this thesis provides two main conclusions. First, evidence from this experiment has indicated action observation with physical practice as an effective rehabilitation tool for improving function of the upper limb in chronic stroke. The study in this thesis was the first based upon the reviewed literature to use a within-subject design. As such, change from control phase to action observation phase specifically highlights the additive value of action observation above that of task-specific practice. The matching of physical practice in the control group to that of the intervention group has not been consistently applied in the previous literature (e.g., cite example study); hence, it is difficult

to clearly determine from the previous literature the additive value of action observation training to improvement in function. This advances theoretical understanding of action observation training based upon behavioural and neural studies, by providing behavioural evidence that more immediate attempt to activate the mirror neuron system coupled with immediate physical practice facilitates greater improvements to functional motor skills in chronic upper limb stroke.

Second, participant-perceived improvements to function are associated with actual functional improvement. That is, as function of the hemiparetic hand and arm improved so did confidence in use of the impaired arm. This indicates that there are concomitant psychological benefits to physical practice alone or additive action observation interventions that attempt to improve function of the impaired arm in stroke. It appears that not only is the mode of intervention important for rehabilitation of the impaired arm, but that the perceived positive psychological benefit it facilitates contributes to functional improvements. Theoretically, this indicates that perceived benefit of the intervention is important for rehabilitation of the impaired arm. Perceived benefit may have motivated the participants to persist and concentrate on relevant phases of the experiment.

Although the use of a within-subject design proved beneficial in some regards (i.e., indicating additive value of action observation and control over individual differences) limitations are presented in controlling carryover effects. Future experimental examination using a randomised control trial design is needed. In this particular design, a placebo-control group may be more useful in isolating whether perception of benefits or action observation per se, or if both contribute to functional improvement in the impaired arm. Additionally, a follow-up retention test is needed to evaluate the durability of functional improvement and benefits gained. These future research initiatives are mere starting points, with numerous possibilities for examining the use of action observation as a stroke rehabilitation tool. An

example of a future direction includes investigation of action observation and physical practice volumes to optimise neuroplasticity and functional improvement and retention of functional improvement(s). As future research is conducted progress can be made to provide a clearly defined clinical dose for action observation so that it can be made widely accessible for stroke survivors.



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